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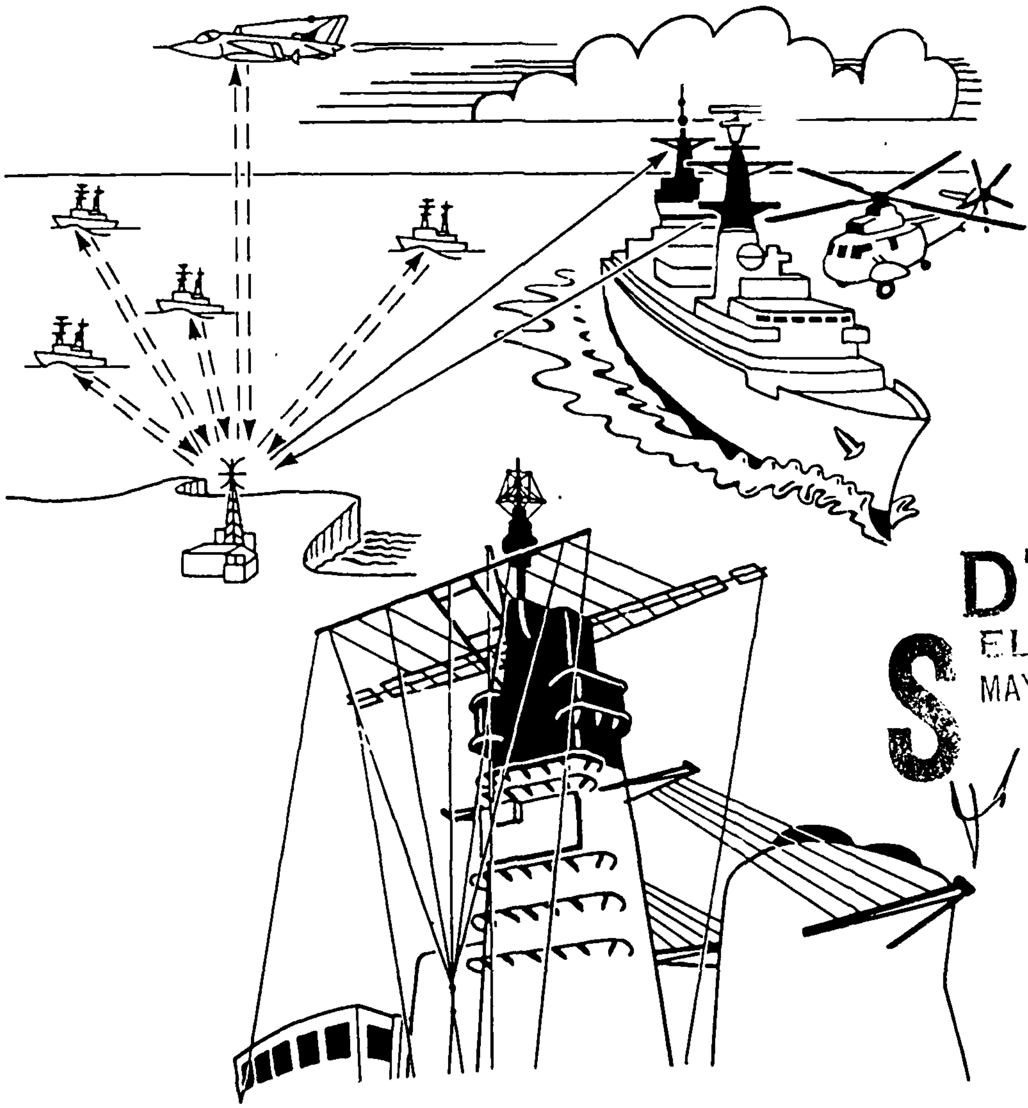
# Fourth International Conference on HF RADIO SYSTEMS AND TECHNIQUES





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A COMPUTER AIDED DESIGN FOR COLLOCATED HF LINKS

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The design and interference analysis of HF communication systems on Navy ships (topside telecommunications design) is a computationally complex and time consuming task. The topside designer must collocate high powered, frequency agile, narrowband and wideband HF transmitters with sensitive receiver systems all sharing a very few number of antenna mounted in a confined area on a ship's superstructure. The interference analysts' task is to predict the degree to which cosite interference prevents the systems from being fully utilized and the degree of interference degradation.

The major problem in HF topside design is cosite electromagnetic interference (EMI). All the transmitters interfere, to some degree, with all the receivers through the couplers, antennas and reflections from the superstructure of the ship. Solutions to the cosite EMI problem span the dimension of space, time, and frequency. Techniques available to the designer to mitigate cosite EMI are to: increase received signal power; change connectivity; increase coupling loss between antennas and between antennas and the reflecting surface of the ship; add filters; use different methods of coupling; reduce maximum allowable transmitter power; decrease duty cycles and the incidence of simultaneous transmission.

There have been many programs and techniques developed over the past decade to deal with the cosite EMI problem. Previous programs have evolved from semimanual to highly automated techniques. However the EMI problem has grown to such an extent on today's ship that system design and analysis requires computer aided tools. COEDS (Communication Engineering Design System) is one of the tools that has been developed to aid in the topside design and interference analysis problem.


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# Contents

# A COMPUTER AIDED DESIGN TOOL FOR COLLOCATED HF LINKS

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## INTRODUCTION

The design and interference analysis of HF communication systems on Navy ships (topside telecommunications design) is a computationally complex and time consuming task. The topside designer must collocate high powered, frequency agile, narrowband and wideband HF transmitters with sensitive receiver systems all sharing a very few number of antennas mounted in a confined area on a ship's superstructure. The interference analysts' task is to predict the degree to which cosite interference prevents the systems from being fully utilized and the degree of interference degradation.

The major problem in HF topside design is cosite electromagnetic interference (EMI). All the transmitters interfere, to some degree, with all the receivers through the couplers, antennas and reflections from the superstructure of the ship. Solutions to the cosite EMI problem span the dimension of space, time, and frequency. Techniques available to the designer to mitigate cosite EMI are to: increase received signal power; change connectivity; increase coupling loss between antennas and between antennas and the reflecting surface of the ship; add filters; use different methods of coupling; reduce maximum allowable transmitter power; decrease duty cycles and the incidence of simultaneous transmission.

There have been many programs and techniques developed over the past decade to deal with the cosite EMI problem. Previous programs have evolved from semimanual to highly automated techniques [1-3]. However the EMI problem has grown to such an extent on today's ships that system design and analysis requires computer aided tools. COEDS (Communication Engineering Design System) is one of the tools that has been developed to aid in the topside design and interference analysis problem.

## COEDS STRUCTURE

COEDS is an interactive work station CAD/CAE tool. The primary use for COEDS is cosite interference analysis of topside communication systems. COEDS consists of five modules: System Input (Block Diagram Editor); Design and Modification (Configuration Data Base); Equipment Data Base; System Analysis (Interference Computation engine); and Performance Evaluation (Postprocessor). The COEDS software structure is shown in figure 1. This figure shows the five modules as rectangles with interconnecting lines representing the data flow.

A communications engineer interacts with COEDS via two of the modules: the Block Diagram Editor for input and the Postprocessor which displays the output in a variety of graphical and tabular modes. The Block Diagram Editor is used to select communication subsystem blocks (transmitters, receivers) for block diagrams from the Equipment Data Base. Block diagrams are stored in the Configuration Data Base and analyzed in the Interference Analysis Module. Each of these software modules is described below.

### System Input

A communication engineer normally thinks in terms of block diagrams. Therefore we designed the user input to COEDS to be in the form of equipment "black boxes" which can be connected to form a block diagram. The block diagram is drawn using a Block Diagram Editor. Equipment blocks are placed on the screen in the diagram by selecting equipment from pop up windows by using a mouse for pointing and selecting. The equipment blocks are connected exactly as the signals would flow from block to block.

Using a mouse, the user can add blocks, delete blocks, change the connectivity, adjust equipment parameters, or move the blocks around on the screen. An advantage in using a mouse for data entry is in error checking and minimizing the possibility of the user entering erroneous data. The user can only select items from the menus and the data base and therefore cannot enter erroneous data. After a block diagram is entered and saved in the Configuration Data Base, COEDS automatically generates all the inputs needed by the Interference Analysis Module for system analysis.

### Design and Modification

The Design and Modification module stores the users' designs, analysis results, and changes to designs in a Configuration Data Base. The Configuration Data Base is an incremental data base that maintains a collection of design states (instances of a block diagram and interference analyses). This allows a user to review a design and the analysis results and compare with other designs or other versions of the same design.

### System Analysis

Cosite interference analysis is done using batch programs supplied by others, written in FORTRAN and BASIC, which were developed prior to and independently of COEDS (written in Lisp). These batch programs are WIDEBAND [3] for interference interactions, LINCAL [4] for link analysis, and Antenna Matching [5] for designing broadband antenna matching networks. COEDS had to be designed to use these "foreign" batch programs as they were and also to accommodate new programs in the future. To be able to incorporate "foreign" batch programs into COEDS regardless of the programming language and development environment, COEDS uses a parser on the input and output of all these programs.

A parser acts as a buffer and a translator between the main line of COEDS and "foreign" batch programs incorporated into COEDS. For example normally a card deck would be required as the input to the FORTRAN program used in WIDEBAND and incorporated in COEDS. However COEDS is an interactive system and card decks are not used. Therefore a parser was developed that generated an input file to WIDEBAND that was similar to the input from a card deck. Also, as the system is interactive and is designed to run with practically no user training or lengthy input from the user, then the input to WIDEBAND must be generated automatically. This is done by the parser.

The output from WIDEBAND is a FORTRAN based file of rows and columns of numbers which are difficult to read and interpret. A parser was used to map the FORTRAN output into a Lisp readable form which can be used in a postprocessor to generate graphs. Using parsers we are able to interface to virtually any "foreign" code without modifying or retesting the code.

## Equipment Data Base

All communication equipment used in a block diagram in COEDS must appear in the COEDS Equipment Data Base. The Equipment Data Base stores equipment operating parameters and performance degradation curves. This data is used to set parameters in a block diagram, calculate interference levels, and analyze system and link performance. However the user must also be able to view the data base to search for pieces of equipment or to check parameters of selected items. In addition to viewing the data base, the user must be able to add special items to the data base (such as filters or couplers) which are nonstandard but are required for a particular design. The user interface to the data base is via a parser. A parser is used to convert all entries in the data base to a Lisp form which can then be processed and displayed to the user.

## Performance Evaluation

The purpose of the Performance Evaluation module (Postprocessor) is to organize and present output data to the user in a thought enhancing manner. The data is shown in a hierarchical and graphical form. This format, which arranges data from the most general to the most specific, permits the user to make quick and accurate design decisions regarding ways to mitigate interference analysis. The user may rapidly decide which data is most pertinent for the particular problem and will have the biggest payback in solving an interference problem.

## COSITE ANALYSIS

Interference analysis and performance prediction in COEDS is based on an analytic model of the interference interactions in a cosite environment. Using either the entire model or just parts of the model separately and running the model in an iterative manner, it is possible to identify all the contributors to an interference problem. This allows the user to quickly identify the parts of a block diagram that must be changed in order to achieve a desired interference margin.

The interference interactions used in the COEDS Interference Analysis module are: Broadband Transmitter Noise, Spurious Emissions, Transmitter Intermodulation, Coupler Intermodulation, Coupler Harmonics, Coupler Crossmodulation, Receiver Adjacent Signal, Spurious Response, and Receiver Intermodulation.

## Cosite Analysis Example

Interference analysis and performance degradation prediction is directed towards achieving a target system performance score for each victim receiver in a block diagram. The system performance score is a probabilistic measure (0-1) of achieving a predefined quality of service (either bit error rate or voice articulation index) in the presence of cosite interference, ambient noise, and receiver intrinsic noise. The user's objective is to reduce the cosite interferers to a level where they are less than the ambient noise and the receiver noise. In other words the interferers are reduced enough so that the system is not interference limited but only limited by ambient noise and receiver noise.

An example of a cosite interference analysis has been done for an HF system shown in figure 2. This HF system has four transmitters, coupler and decoupler, and three antennas. To simplify the example only one victim receiver is shown. Additional victim receivers would be treated in an identical manner as in the example. Due to the space limitations of this paper only a single example of COEDS is shown. The purpose of the example is to show: a typical COEDS input form; the method of showing interference interactions and performance degradation; the steps used to divide the analysis problem into manageable pieces; and the iterative approach used in COEDS to identify and reduce specific interference interactions. The example is for illustration purposes only and is not intended to represent an actual system.

The example analyses follows four steps: 1. Adjacent signal analysis to determine minimum transmitter-receiver frequency spacing; 2. Intermodulation analysis to determine undesirable frequency combinations and maximum allowable transmitter power; 3. Frequency selection and system connectivity adjustments in order to mitigate problems discovered in the first two steps; 4. Receiver performance degradation calculation from all system interference interaction models. Because of the ease of changing the system configuration and automatic changes to the data base, the system may be changed at any time and any step during the analyses. Rapid changes to the system allows the use of an iterative approach to improve the system until the desired performance score is achieved.

The results of the adjacent signal analysis for the example system are shown in figure 3. The receiver frequency is shown dotted in the middle of the frequency axis at 3 MHz. The adjacent signals from transmitters are shown with antenna symbols symmetrically spaced on each side of the receiver frequency at frequency spacings of ±2.5%, ±5% and ±10%. The vertical axis shows the excess interference level (EIL) from each adjacent signal. The excess interference is the amount by which an interaction exceeds the level required in order to achieve a predefined performance score. An EIL value of 0 dB or less is the goal and would allow the system to meet the users target performance score.

The table below figure 3 lists the 20 most severe adjacent signal interactions in order of decreasing EIL. Each transmitter was evaluated for receive adjacent signal (RAS) interference and transmit adjacent signal (TAS) interference at transmit-receive frequency spacings of ± 2.5%, 5%, and 10%. Therefore each transmitter is shown in the graph at several different frequencies. As shown in the graph and in the table, the worst interferer is transmitter 1, which is shown in the top 12 entries.

Figure 3 shows that as the transmit-receiver frequency separation increases, the adjacent signal interference levels are reduced. To reduce the adjacent signal interference to an EIL value of 0 dB (goal) without requiring extremely large frequency spacing, either the connectivity can be changed or the equipment can be changed. For the example we have changed the method of coupling transmitter 1 and receiver 1 (victim receiver) to antenna 1 by adding two additional couplers. The revised system was entered into COEDS and is shown in figure 4. The effect of this change was to reduce the adjacent signal interference in the victim receiver. The results are that if transmitter 1 is operated at a spacing greater than ±5% and the other transmitters operated at a spacing greater than ±2.5% from the victim receiver, then adjacent signal interference will not limit system performance.

The analysis was continued with an intermodulation study. The transmitter frequencies were initially set at 2.0, 4.5, 6.0 and 2.5 MHz for transmitters 1-4. The receiver was set at 3.0 MHz. The initial results showed that transmitter intermodulation was excessive from transmitters 2 and 3, producing an intermodulation product in the victim receiver passband. Transmitter 3 frequency was shifted 100 Khz to 5.9 Mhz and the analysis redone. The result after changing the transmitter frequency was that all the EIL values for transmitter intermodulation were reduced to 0 dB or less so the system will not be modified further, see figure 5

An additional step in the analysis example was to investigate the link range between the victim receiver and a remote transmitter. Typically the range is limited by cosite interference, ambient noise and receiver intrinsic noise. The objective in cosite analysis is to reduce the interferers to a level where they do not limit the link range. Figure 6 shows the difference between noise limited service and interference limited service. Figure 6 has two curves. The top curve shows link range when the system is only limited by ambient noise and receiver noise. The bottom curve shows the link range when the link is limited by interference. The interference limited case was produced by setting transmitter 1 operating frequency at 2.5% spacing from the victim receiver. This spacing violates a constraint derived in the adjacent signal analysis and produces an excess interference level of +6 dB. The effect of the excess adjacent signal interference is to reduce the maximum link range by approximately 30 Km.

The results of the cosite interference analysis show the user how to choose frequencies, power, connectivity, equipment parameters and other system details to ensure that the system is not constrained by cosite interference. Alternatively if a system is interference limited and cannot be changed, COEDS could be used to calculate the necessary received signal power to overcome the interference and achieve the desired performance score. An increase in the necessary received signal power may be translated directly to a reduction in range.

Another application for COEDS is investigating the effect of violating system design constraints. For example one could calculate the effect on a victim receiver of increasing the power of a transmitter by 10 dBm or operating a transmit-receive frequency pair closer than the calculated minimum spacing. Other possibilities are to determine the effect of the VSWR of an antenna or coupler on the system performance by using the antenna matching program in COEDS.

## SUMMARY

COEDS is an interactive CAD/CAE work station tool. COEDS may be used to analyze electromagnetic interference (EMI) in topside HF communication systems and may be used as a guide to mitigate cosite interference. An example was shown which demonstrated: a system configuration can be entered directly as a block diagram using a mouse; user inputs are simple, constrained to menus and data base entries so that errors are minimized; all inputs to the analysis modules are generated automatically; the system configuration may be easily changed and quickly reanalyzed; interference levels are shown in graphical and tabular form; and link range may be calculated on the basis of cosite EMI. Some of the key features of COEDS are: the Block Diagram Editor which operates from a mouse and an equipment data base; a configuration data base which stores instances and changes to system designs; the integration of foreign batch programs; and the initial design of a post processor to produce a "thought enhancing output."

## References

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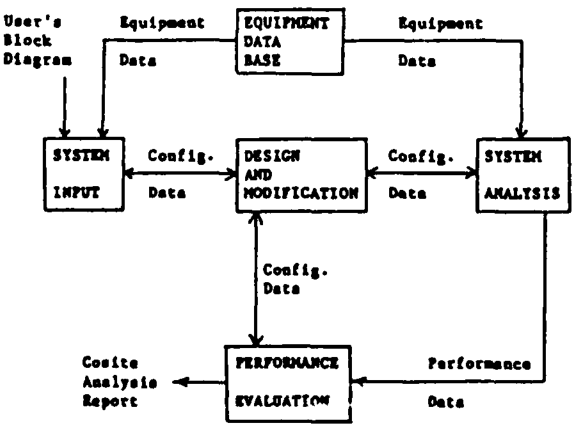


Figure 1 COEDS Software Structure

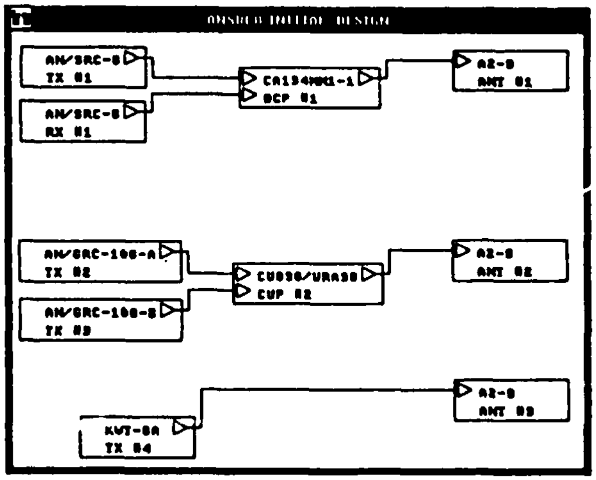


Figure 2 Example HF System

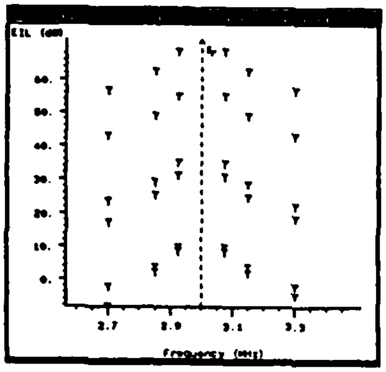


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Figure 3 Adjacent Signal Interference Analysis

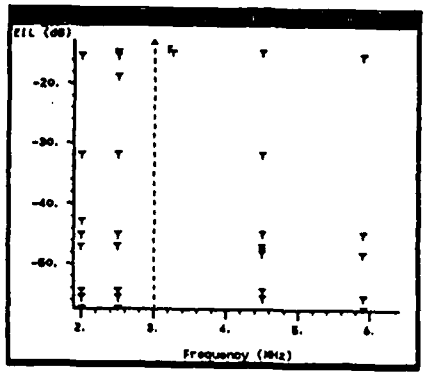


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Figure 5 Intermodulation Interference Analysis

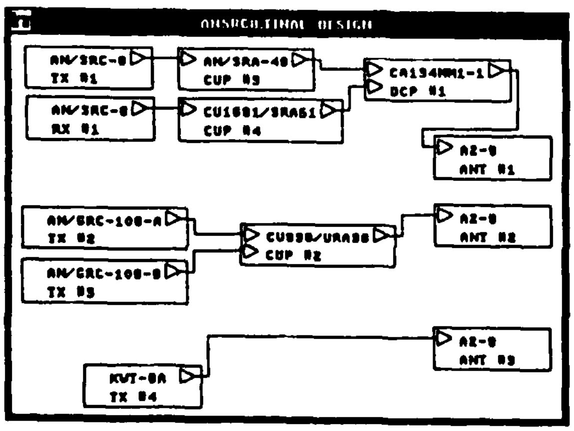


Figure 4 Revised Example HF System

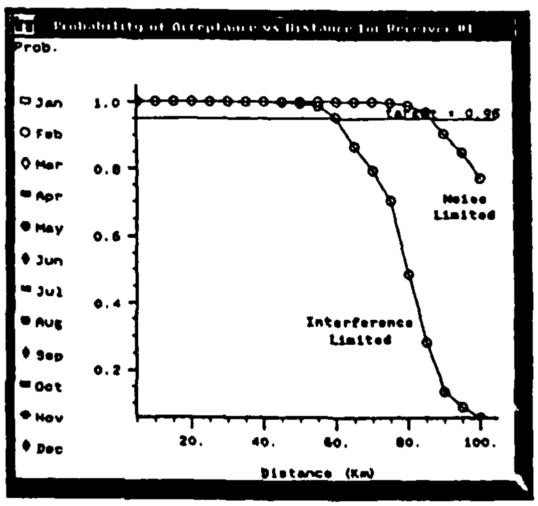


Figure 6 HF Link Distance vs. Reliability